

Research Note

Vine and Berry Response of Merlot (*Vitis vinifera* L.) to Differential Water Stress

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Abstract: Merlot vines were drip-irrigated with 100, 70, or 35% of estimated crop evapotranspiration (ET_c) or 35% ET_c until veraison followed by 70% ET_c until harvest. Midday leaf water potential (Ψ) differed among irrigation regimes and ranged from -0.9 to -1.7 MPa, with a 0.3 to 0.5 MPa difference between 35 and 100% ET_c . Decline in shoot growth, berry size, cluster weight, yield, trunk growth, cluster number, and berry titratable acidity corresponded with a decline in Ψ . Increasing irrigation from 35 to 70% ET_c at veraison consumed 30% less water producing similar yield and quality as the 70% ET_c treatment.

Key words: winegrape, evapotranspiration, leaf water potential, regulated deficit irrigation

The Western Snake River Plain in southwestern Idaho (~43°N, 114°W, elevation 695 to 890 m) is an emerging viticulture production region with a warm, arid climate. The high evaporative demand of this region necessitates supplemental water for crop production and provides an opportunity to manipulate grape vine and berry attributes through water management (Smart and Coombe 1983). Vine water stress is thought to enhance fruit quality for wine production (Jackson and Lombard 1993), but may at the same time impact vineyard profitability by reducing berry size and lowering yield. The importance of phenological timing on vine and berry response to water stress (Hardie and Considine 1976) is reflected in a strategy known as regulated deficit irrigation, whereby water stress is imposed and alleviated at periods of rapid vegetative and fruit growth, respectively (Goodwin and Macrae 1990). It is well established that vine water stress reduces berry size and yield (Matthews et al. 1987, Matthews and Anderson 1988, 1989, Hamman and Dami 2000, Salon et al. 2005) and that reduction in size is greatest when the stress occurs pre- rather than postveraison (Matthews et al. 1987, Matthews and Anderson 1988). Less well studied is vine and berry response to alleviation of preveraison water stress during postveraison ripening. The contradictory re-

sults in response to differential water stress for phenology (Hardie and Considine 1976, Hepner et al. 1985, Matthews et al. 1987, Matthews and Anderson 1989), reproductive capacity (Buttrose 1974, Matthews and Anderson 1989), and berry composition (Esteban et al. 1999, Salon et al. 2005), are difficult if not impossible to explain because many studies lack a common biological indicator of vine water status. Leaf water potential (Ψ), determined by means of a pressure chamber (Scholander et al. 1965), corresponds with soil moisture and leaf gas exchange (Williams and Araujo 2002) and may be a useful, biological measure of vine water status that would enable comparison of vine and berry response to water stress independent of growing region.

Little published information is available on response of Merlot grapevines to water stress under field conditions, and none is available on its response to deficit irrigation under the climatic conditions and soils of southwestern Idaho. The objective of this research was to use the pressure chamber to relate midday Ψ to vine and berry response under differing severities of preveraison water deficit that was either sustained until harvest or alleviated at veraison.

Materials and Methods

The trial was established spring 2002 at a 152-ha commercial vineyard near Nampa, ID (lat: 43°2'N, long: 116°42'W, elevation 841 m), along the southern perimeter of a mature (4-year-old), 12-ha block of own-rooted *Vitis vinifera* L. cv. Merlot. Vine rows were oriented north to south with row-by-vine spacing of 2.4 by 1.8 m (~2242 vines/ha). Each vine had two trunks, with each trunk forming a unilateral, 90-cm long cordon ~1 m above soil surface. Cordon arms were spur-pruned (seven 2-bud spurs per cordon) and vertically trained between two sets of moveable foliage wires. Soil type was a well-drained Scism calcareous silt loam aridisol with ~45 cm of wind-laid silty deposit above a calcareous layer of silt loam (U.S.D.A.

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1972). The upper 60 cm of soil had a pH of 8.1, 1.8% organic matter, and 1 mmhos cm^{-1} electrical conductivity.

The trial had 16 plots with each plot containing four rows of 14 vines per row (56 vines). Water supply to each plot was independently delivered by a programmable controller (Nelson model 8071 and 8032; SoloRain, Peoria, IL) and aboveground drip line with two punch-in, 2-L h^{-1} emitters located 15 cm on either side of each vine and was measured by an in-line flow meter (Master Meter Multijet, Mansfield, TX). With the exception of irrigation scheduling, vines were managed according to standard commercial practice that included row cover-crop maintenance, weed removal, pesticide application, and nutrient management.

Vines were provided weekly with 35, 70, or 100% of estimated crop evapotranspiration (ET_c) beginning just after fruit set until at least two weeks after harvest (duration of 111, 114, or 99 days for each year, respectively). In a fourth irrigation regime, 35% ET_c was provided until veraison followed by 70% ET_c through the postharvest period. These irrigation regimes are hereafter referred to as 100, 70, 35, and 35–70% ET_c . Irrigation treatments were randomly allocated to plots in a block design with four replications. Trial plots were irrigated close to field capacity at the beginning and end of the growing season and as needed between budbreak and bloom to maintain Ψ above -1.0 MPa. Differential irrigation began after fruit set when Ψ was \leq -1.0 MPa. Irrigation amount was calculated weekly by multiplying reference evapotranspiration (from U.S. Bureau of Reclamation Nampa weather station <http://www.usbr.gov/pn/agrimet/wxdata.html>) by a winegrape crop coefficient (Evans et al. 1993), projected number of days until the next irrigation, and desired percentage of ET_c . The calculated amount of water for each treatment was delivered weekly by altering irrigation duration. Midday Ψ was measured weekly with a pressure chamber (model 610; PMS Instruments, Corvallis, OR) as described elsewhere (Turner 1988) on two leaves from interior vines in each plot within one hour after solar noon on the sixth day after each irrigation beginning 42 days after budbreak.

Three vines in the middle interior two rows of each plot were used to measure shoot length, berry diameter, seasonal trunk growth, clusters per vine, and percent canopy transmission of photosynthetically active radiation (PAR) in the fruiting zone. Shoot length and berry diameter were measured weekly and trunk diameter was measured after the first and last irrigation of each season. The clusters on each data vine were harvested, counted, weighed, and used to calculate yield per vine and average cluster weight per vine. PAR in the fruiting zone of data vines was measured one hour after solar noon with a ceptometer (AccuPAR PAR-80; Decagon Devices, Pullman, WA) one month before harvest in 2002 and 2004. Percent transmission was expressed as the ratio of canopy to ambient PAR, multiplied by 100.

Berry weight and must acid and soluble solids content were measured from a sample of 10 clusters harvested equally from the east and west side of each data vine.

Two berries from each of five cluster locations (four cardinal quadrants and center) were used to determine the weight of 100 berries. The remaining berries in the 10-cluster sample were passed through a hand-operated crusher and the must used to measure percent soluble solids, pH, and titratable acidity. Must percent soluble solids was measured with a Mettler Toledo RE40 (Columbus, OH) digital bench-top refractometer, and pH and titratable acidity were analyzed in sequence with an autotitrator (Brinkmann Metrohm 716 DMS Titrino; Herisau, Switzerland) from 40-mL undiluted juice using 0.2 N NaOH.

Weekly mean values for measurements of Ψ , shoot length, and berry diameter were graphed with standard error bars using SigmaPlot 2000 (version 6.1; SPSS Inc., Chicago, IL). Data describing berry and vine attributes were analyzed separately by year using analysis of variance appropriate for a randomized block design (general linear model, SAS version 8.02; SAS Institute, Cary, NC) with irrigation regime as the main effect. Probability of significant difference among treatments was determined from an F-test with irrigation by replication as denominator error mean square. Significant ($p \leq 0.05$) irrigation treatment means were separated using Duncan's multiple range test ($p \leq 0.05$).

Results and Discussion

The volume of water applied to trial plots during differential irrigations was within 5% of targeted ET_c . The average amount of water applied to 35–70% ET_c plots was 34% (2002, 2004) or 22% (2003) less than the 70% ET_c plots (Table 1). The duration of preveraison water stress was shortest in 2004 because of spring precipitation. Average cumulative growing season reference evapotranspiration and growing degree days (Table 1) were slightly (~3%) higher than the 1535.8 growing degree days and 1268.1 mm ET_r reported for southcentral Washington (Evans et al. 1993). Irrigation water applied to 100% ET_c trial plots combined with growing season precipitation ranged from 476 (2004) to 547 mm (2002), which is ~25% higher than the 387 to 432 mm consumption from lysimeter data reported for well-watered winegrapes in southcentral Washington (Evans et al. 1993).

Pre- and postveraison Ψ responded to differential irrigation and ranged seasonally from -0.80 to -1.75 (Figure 1). Differential irrigation started when the vines were postbloom at growth stage 25 (day of year 170 in 2002 and day of year 168 in 2003) or 31 (day of year 188 in 2004) (Coombe 1995). The weekly Ψ of 100% ET_c vines was about 0.3 to 0.5 MPa higher than that of 35% ET_c vines three to four weeks after start of differential irrigation (day of year 190 in 2002, 196 in 2003, and 210 in 2004), and remained higher until harvest (Figure 1). Preveraison weekly Ψ under 100% ET_c fluctuated around -1.0 MPa (2002 and 2004) or -1.2 MPa (2003) and around -1.3 MPa (2002, 2003, and 2004) under 35 or 35–70% ET_c . The preveraison Ψ under 70% ET_c was usually intermediate

between the 100 and 35% ET_c treatments. Postveraison Ψ tended to decline about 0.2 MPa, and vines under 35–70% or 70% ET_c treatments were intermediate between 35 and 100% ET_c (about -1.4 MPa in 2002 and 2003 and -1.2 MPa in 2004).

The midday Ψ of vines under 100 or 70% ET_c in this study was similar to well-watered or moderately stressed grapevines in field trials conducted in Spain on cultivar Bobal (Salon et al. 2005) and various cultivars in Califor-

Table 1 Growing degree days, reference evapotranspiration (ET_r), precipitation, and water provided to Merlot irrigation field trial plots in southwestern Idaho in each of three consecutive growing seasons.

	2002	2003	2004
Growing degree days ($^{\circ}C$) ^a	1505	1757	1517
ET_r , Apr 1 – Oct 31 (mm)	1278.9	1381.5	1261.4
Annual precipitation (mm)	98.8	188.7	258.8
Apr 1– bloom (Jun 13)	36.8	47.0	80.5
Bloom – veraison (Aug 14)	2.3	14.2	16.8
Veraison – harvest (Sep 20)	4.1	6.9	26.7
Differential irrigation (mm)			
100% ET_c	368.4	331.2	233.7
70% ET_c	262.0	242.8	158.5
35% ET_c	131.8	122.9	78.8
35–70% ET_c	171.7	190.0	103.9
Supplemental water (mm)	135.6	134.9	118.6

^aAlfalfa reference crop (lat: 43°26'N; long: 116°38'W, elevation 790 m) (<http://www.usbr.gov/pn/agrimet/wxdata.html>). Growing degree days Apr 1 to Oct 31 calculated by simple daily average with base 10°C and no upper threshold using the northwest berry and grape degree-day calculator (<http://berrygrape.oregonstate.edu/resources/weather.htm#Idaho>).

nia, including Merlot, Cabernet franc, Chardonnay, Cabernet Sauvignon, Syrah, and Zinfandel (Greenspan et al. 1996, Williams and Araujo 2002, Matthews and Anderson 1988). The responsiveness of Merlot Ψ to differential water regimes observed in this study was also observed in Napa Valley, California, where Ψ values ranged from -0.7 to -1.8 MPa (Williams and Araujo 2002) and in Napa Valley-grown Cabernet franc where a 0.3 MPa difference in Ψ was reported between deficit and well-watered vines (Matthews et al. 1987).

Decline in main shoot growth was apparent as Ψ approached -1.0 MPa and preceded (2002) or coincided with (2003, 2004) the first differential irrigation (Figure 1). Inhibition of main shoot growth at a Ψ of -1.0 MPa has also been reported for grafted Merlot, Cabernet Sauvignon, and Pinot gris in Sonoma County, California (Greenspan 2005). The similarity in sensitivity of main shoot growth to Ψ under different soil and climatic conditions for own-rooted as well as grafted Merlot and other cultivars suggests that early-season Ψ could be used in regions with little or no growing season precipitation to target a main shoot length through irrigation scheduling.

Yield of Merlot was reduced up to 48% under deficit irrigation (Table 2). The yield reduction was associated with smaller berries, lower cluster weight, and fewer clusters per vine. Vines under 70% ET_c had similar harvest berry weight, cluster weight, and yield as vines under 100% ET_c . Plots under 35% ET_c yielded consistently lower than 70% ET_c and 25 to 48% lower than 100% ET_c . Yield, cluster weight, and harvest berry weight of vines under 35–70% ET_c were similar to 70% ET_c in two out of three years and 16 to 38% lower than 100% ET_c . Veraison berry diameter under 35 or 35–70% ET_c was similar but smaller than 100% ET_c in two out of three years. Results from this study suggest that alleviating water stress severity

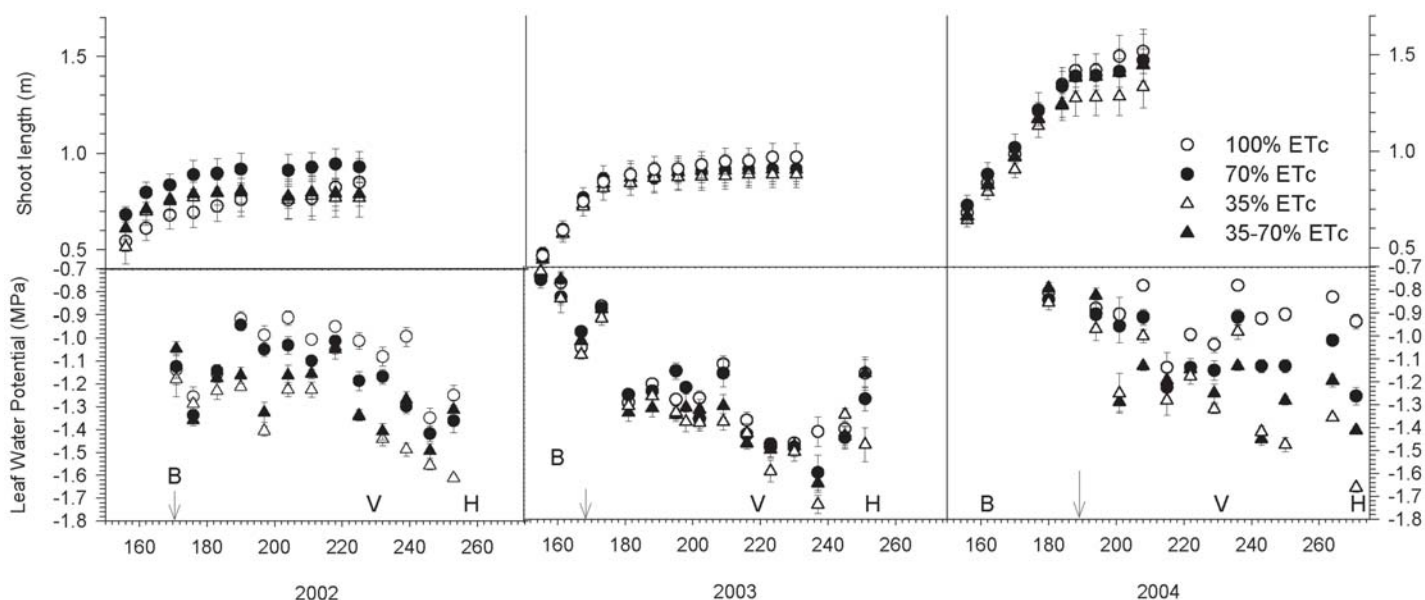


Figure 1 Shoot length and midday leaf water potential of own-rooted Merlot vines subjected to differential irrigation regimes during a multiyear field trial in southwestern Idaho. Arrow depicts start of irrigation treatment. B, V, H indicate bloom, veraison, and harvest. Bars represent one standard error.

Table 2 Response of Merlot grapevines to differential irrigation over three growing seasons in southwest Idaho.

	Canopy				Veraison berry diam (mm)	Harvest berry wt (g/berry)	Harvest cluster wt (g/cluster)	Yield (kg/vine)
	Irrigation level (% ET _c)	Light trans. (%)	Trunk growth (mm)	Clusters (no/vine)				
2002	100	5.9 a ^a	3.3 a	—	9.9 a	1.01 a	172 a	6.1 a
	70	14.1 b	2.2 b	—	9.3 a	0.89 a	168 a	5.3 a
	35	17.2 c	2.1 b	—	8.5 b	0.67 b	112 b	3.2 b
	35–70	18.5 c	1.6 b	—	8.2 b	0.61 b	124 ab	3.8 b
2003	100	—	3.1 a	46.6 a	9.7 a	1.16 a	148 a	6.9 a
	70	—	2.6 ab	45.5 a	9.4 ab	1.07 ab	132 ab	6.1 ab
	35	—	2.2 b	38.8 b	9.1 b	0.92 c	105 c	4.1 c
	35–70	—	2.7 ab	43.9 ab	9.1 b	0.97 bc	123 bc	5.4 b
2004	100	0.8 a	3.8 a	55.4 a	10.0 a	1.34 a	194 a	10.4 a
	70	0.9 a	3.7 a	54.9 a	10.0 a	1.33 a	177 ab	9.6 ab
	35	1.2 a	3.7 a	47.4 a	9.7 a	1.22 a	168 b	7.8 c
	35–70	0.8 a	3.5 a	49.6 a	10.0 a	1.31 a	178 ab	8.7 bc

^a Same letter within a column year indicates no significant difference at $p \leq 0.05$, Duncan's multiple range test.

postveraison can compensate for undesirable yield reductions and supports findings for Napa Valley-grown Cabernet franc (Matthews and Anderson 1989). The changes in yield components associated with vine water stress observed in the present study are in the range reported by others (Hardie and Considine 1976, Salon et al. 2005, Esteban et al. 1999, Matthews and Anderson 1989).

The 100% ET_c irrigation treatment had, in general, the lowest percent canopy light transmission, the greatest seasonal trunk growth, and the greatest number of clusters per vine (Table 2). Annual trunk growth of vines under deficit irrigation was 20% (2003) or 40% (2002) less than vines under 100% ET_c, and in one year vines under 35% ET_c had fewer clusters than 100% ET_c. These trends support other findings that show a reduction in trunk growth (Myburgh 1996) and bud fruitfulness (Buttrose 1974, Esteban et al. 1999, Matthews et al. 1987, Matthew and Anderson 1989) under water stress. The increase in fruitfulness and trunk growth observed in 2003 under 35–70% ET_c suggests that these traits are sensitive to post-veraison vine water status. Similarity among treatments in 2004 was likely due to early-season precipitation.

The pattern of berry growth observed in this study was a typical double-sigmoid curve with onset and duration of berry development similar among treatments despite relative differences in magnitude of growth (Figure 2). The 3-year-average duration of berry development for stages I through III was 46, 15, and 37 days, with onset of veraison and harvest corresponding to 1200 and 1560 accumulated growing degree days (April 1, base 10°C). These berry stage durations are similar to that reported by Kennedy (2002) and to relative growth stage durations for container-grown Cardinal (Matthews et al. 1987). The similar pattern of berry development under differential water stress observed in this study supports the findings

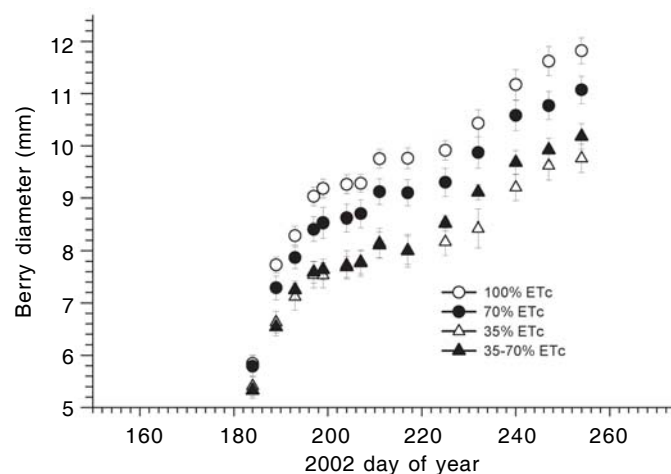


Figure 2 Weekly change in diameter of Merlot berries located on the east and west side of the canopy of vines subjected to differential irrigation regimes in a multiyear field trial in southwestern Idaho. Bars represent one standard error.

of others for field-grown Bobal, Tempranillo, and Cabernet franc (Salon 2005, Esteban et al. 1999, Matthews and Anderson 1989).

A reduction in must titratable acidity was apparent under deficit irrigation, yet soluble solids concentration was either similar (two out of three years) or slightly higher under 35 or 35–70% ET_c (2002) (Table 3). A reduction in titratable acidity associated with water deficits has been attributed to reduction in malate (Matthews and Anderson 1988, Esteban et al. 1999). In this study, a difference in soluble solids among irrigation regimes was apparent only in 2002, the year of greatest difference in yield per vine, where the 35 and 35–70% ET_c treatments had highest soluble solids, lowest yield per vine, and highest canopy light transmission.

Table 3 Berry composition from Merlot grapevines in response to different irrigation levels over three growing seasons in southwest Idaho.

	Irrigation level (% ET _c)	Brix (%)	Titrateable acidity (g/L)
2002	100	25.3 a ^a	5.9 a
	70	25.6 ab	5.9 a
	35	26.2 bc	4.7 b
	35–70	26.7 c	5.0 b
2003	100	22.8 a	4.6 a
	70	23.4 a	4.0 b
	35	22.9 a	3.6 c
	35–70	22.8 a	3.7 bc
2004	100	22.4 a	4.8 a
	70	21.8 a	4.2 b
	35	22.5 a	4.3 b
	35–70	22.2 a	4.1 b

^a Same letter within column year indicates no significant difference at $p \leq 0.05$, Duncan's multiple range test.

Conclusion

Differential, ET_c-based irrigation scheduling was used in this study to measure midday Ψ and vine and berry response to incremented levels of vine water stress. Results suggest that midday leaf water potential, determined by means of a pressure chamber, is a useful biological indicator of vine water status and can be used to compare vine and berry response to water stress independent of growing region. In warm, arid growing regions, midday Ψ may also be used to facilitate irrigation scheduling. The vine and berry response to midday Ψ values in this study clarify contradictory results in the literature and serve as a guide for future deficit irrigation studies. Results demonstrate water conservation and beneficial yield and berry quality attributes associated with alleviation of preveraison water stress at veraison (35–70% ET_c) compared to a sustained percentage of ET_c between fruit set and harvest (30 or 70% ET_c). A preveraison midday Ψ of -1.3 MPa sustained throughout the growing season (35–70% ET_c) realized an average water savings of 30% with similar yield as 70% ET_c sustained between fruit set and harvest. Investigation of other berry components known to impact wine quality was beyond the scope of this study but should be considered before formulating an irrigation strategy for Merlot.

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